Biology and the Chesapeake Bay

Francis S. L. Williamson[1]

Chesapeake Bay Center for Environmental Studies, Smithsonian Institution, Route 4, Box 622, Edgewater, Maryland 21037

ABSTRACT

Threats to the biological productivity of the Chesapeake Bay have grown in magnitude and complexity as correlates of diverse social, economic, and engineering developments engendered by an ever increasing bayside human population. There is growing agreement that the biological problems have evolved as a result of failure to (1) recognize the Bay (and its watershed) as a large, complex system, and (2) to deal with its problems as parts of an interrelated whole. Each sector of the public and private interest has used and/or abused this common resource in a manner deficient in concern for the resultant *combined and cumulative* effects of these uses on the physical, chemical, and ultimately the biological, state of the system. Problem areas must be delineated and research priorities established to provide the direction for federal, State, and university laboratories that allows them to be more responsive to the needs of management and regulatory agencies, and the society these agencies serve. The current *modus operandi* of many laboratories is ineffectivc for ecological problem-solving, and can be corrected only by the development of appropriate methodologies, by more rigid programming and direction of research, and by improved liaison with managers and planners.

The title of this symposium, "The Fate of the Chesapeake Bay", has a gloomy, almost ominous ring that, unfortunately, may be altogether appropriate. The use of the word *fate* (from the Latin *fatum* = oracle, prophetic declaration), and its definition as that principle, or determining cause or will, by which things in general are supposed to come to be as they are, or events to happen as they do, or foreordination by which either the universe as a whole or particular happenings are predetermined, implies to me that we are little more than chroniclers of events over which we exercise surprisingly meager control. This paper is an attempt to examine the extent to which this is true, at least with respect to our present and prospective ability to deal with the biological problems of the Chesapeake Bay in such a way as to insure its continued functioning as a productive biological system.

The present generation of symposia on the Chesapeake Bay began a little over 3 years ago (Sept., 1968) with the Governor's Conference at Wye Institute. That meeting was particularly well attended by a group that included teachers, scientists, industrial executives, businessmen, government officials from many local, State, and federal organizations, and officers and representatives from trade organizations, conservation and voter groups. The conference was conducted in what seemed to be an almost festive manner, perhaps stemming from a more or less general, and a more or less subliminal, belief that so many important people could not possibly assemble to discuss so many matters of concern about a major natural resource without the emergence of definitive solutions to management problems. In fact, virtually every speaker offered recommendations ranging from the need for more re-

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[1] Dr. Williamson received his B.S. degree (Zoology) from San Diego State College, his M.A. (Ecology) from The University of California, and his Sc.D. (Ecology, Pathobiology) from The Johns Hopkins University. He serves on the Steering and Advisory Committees of the Chesapeake Bay Study (Corps of Engineers), the Research Planning Committee and Steering Committee of the Chesapeake Research Consortium, Inc., the Board of Directors of the Chesapeake Environmental Protection Association, and the Power Plant Siting and Human Health and Welfare Studies Group (Maryland Department of Natural Resources). He serves as Director of the Chesapeake Bay Center.

search of all kinds on just about everything in, on, or around the Bay, to a review of proposed and potential management schemes by Federal agencies, 6 and 7 specific management goals for State and local governments, respectively, and ending with a grand plan for organizing a coordinated resources management structure (The Chesapeake Bay Conservation Commission) for the Bay (Proc. Gov. Conf. Chesapeake Bay, 1968). During the concluding discussions of that first multi-institutional, interdisciplinary conference, however, the question was raised as to just *what* had been accomplished as a result of the lengthy deliberations, and the remark was made that the conference had supplied a very good platform on which to base another conference. Indeed, the Steering Committee recommended similar meetings, i.e., ones directed toward the orderly development of Chesapeake Bay, at 2-year intervals.

Since that first of the super-conferences, a host of somewhat less impressive symposia and conferences have been sponsored by a variety of agencies, and seemingly endless rhetoric has been dedicated to (1) revealing the status of our knowledge of this vast estuary; (2) delineating the problems that are steadily, almost inexorably, reducing its value for diverse and often conflicting uses; and (3) issuing endless recommendations for solutions of these problems. Perhaps this kind of interplay is necessary for the development of solutions to the many problems confronting the Bay, and we have not substituted rhetoric and verbiage for more substantive progress. We must all hope so because conferences, symposia, workshops and so on, are expensive and time-consuming enterprises, and we are in real need of time and money for the solution of clearly identified existing problems, as well as those we know are surely to come.

The Chesapeake Bay, like so many other large natural systems, has demonstrated a remarkable degree of resiliency in its capacity to withstand, and/or to recover from, literally hosts of deleterious, man-induced perturbations. Not only is this capacity likely enhanced as a result of a biota adapted to the naturally unstable conditions that characterize any estuary (Caspers, 1967), but it is made the more striking because of the vastness of this particular system. The widely varying temperature, salinity, and turbidity that are associated with tidal cycles and the mixing of fresh and ocean waters in the Bay tend to mask and to ameliorate changes due to man's activities, especially those that are simply the acceleration of otherwise natural processes. Unfortunately, the exponential increase in such accelerations, combined with a seemingly endless variety of novel abuses, is now reflected by adverse and grossly manifest changes in the system. Seasonal fish kills are relatively commonplace, large algal blooms are phenomena so conspicuous as to be observed by laymen, municipal beaches have been closed for swimming, oil spills are not uncommon, approximately 70,000 acres of shellfish beds are closed, and the annual harvest of oysters has dropped from 8-10 million bushels to 2-3 million. There is general recognition, even among observers of modest sophistication, that there exist serious threats to the continued maintenance of a high level of biological productivity of the Chesapeake Bay, and that these problems are growing in magnitude and complexity as correlates of diverse social, economic, and engineering developments engendered and demanded by a bayside human population that is increasing at an annual rate of about 1.7%. The human population within the drainage area of the Chesapeake Bay, estimated to be 11 million persons in 1960, is projected to increase to 30 million persons within the next 40-50 years. For this population the Chesapeake Bay is a natural resource available for a multiplicity of uses, many of which conflict. It is not realistic to expect, after a review of the decisions that have been made, that are currently being made, and the ones that will need to be made in the immediate future, that this estuary can possibly have other than steadily increasing use as a channel for commerce, and as a sink for disposal of industrial and domestic wastes. It is difficult, if not impossible, to predict whether the Bay can continue to be used for these purposes to a greater extent each day, month, and year and still function productively as a biological system. If not, it will almost certainly cease to function as a recreational and esthetic resource. Already, several of the major tributaries have ceased to have biological, and thus recreational and esthetic, value, signs of similar changes are apparent in others, and disturbing changes are seen in the main stem of the Bay.

I believe that this introduction serves to outline a disturbing trend, i.e., the inability of our scientific and political systems to cope with the problems evolving from the staggering multiplicity of conflicting uses of a large, complex natural system.

The Biological Significance of the Chesapeake Bay

Like other estuaries, the Chesapeake Bay is a remarkably productive biological system. An excellent recent review of the role of the Bay has been provided by Masmann (1971). The shallow, warm waters of the myriad sub-estuarial systems, such as the lower reaches of the Patuxent River, possess phytoplankton communities that fix 1-3 g carbon/cm^2/day, or the equivalent of 2-3 tons of plant production/acre annually (Stross and Strottlemeyer, 1965). Even more important as units for primary production are the 400,000 acres of wetlands that border much of the Bay; an area equivalent in size to 28% of the surface area of the Bay's tributary system (main stem to head of tide). Production of vegetation on marshes in Virginia, principally grasses in the genus *Spartina*, has been shown to average 5.1 tons/acre annually, and to be as great as 10 tons (Wass and Wright, 1969). The diverse functions of wetlands, and their major role in the functioning of the estuarine ecosystem, has been characterized by Cronin and Mansueti (1971) as follows: "... they are organic factories, traps for sediments, reservoirs for nutrients and other chemicals, and the productive and essential habitat for a large number of invertebrates, fish, reptiles, birds and mammals. Annual plant growth and decay, providing continuing large quantities of organic detritus, is one of the major components of the cycling of nutrients in estuaries." Secondary productivity is equally impressive. The annual harvest of fish, including both sport and commercial catches, is about 125 lb/acre, with a potential for harvesting 600 lb./acre (McHugh, 1967). In 1966, the commercial harvest of finfish (303.6 million lb.), oysters and clams (27.8 million lb.), and blue crabs (95.1 million lb.) totalled 426.5 million lb. Adding the annual sport catch of 22 million lb. (Stroud, 1965) brings the total harvest of recent years to nearly one-half billion pounds. Nearly two-thirds (63%) of the commercial catch of fish on the Atlantic coast are species believed to be estuarine-dependent (McHugh, 1966). At present levels of development of the fisheries, this is equivalent to about 535 lb./acre of estuaries; i.e., for each acre of estuary destroyed there could be a loss in yield of 535 lb. of fisheries products on the continental shelf (Stroud, 1971). Many birds, including approximately 350,000 Canada geese, 550,000 ducks, 50,000 whistling swans, and hosts of shorebirds are dependent on the Chesapeake Bay as a wintering area (Masmann, 1971). Eagles, ospreys, herons, gulls, and terns are important nesting species. Important mammals associated with the Bay include the muskrat, raccoon, land otter, and mink.

The biological significance of the Bay is manifest in another extremely important way; its use as a recreational resource. Swimming, boating, fishing, hunting, and other recreational activities have become increasingly important as the human population has grown. As pointed out in *The Chesapeake Bay Plan of Study* (1970), accelerating urban development, an abundance of leisure time, and a generally expanding level of personal income have created in the Bay area a great demand for water-based recreation. The industrial and economic base of the prosperity that generated the demand also threatens to destroy the existing recreation potential by its deleterious effect on the water quality that maintains the integrity of the aquatic environment upon which water-based recreation depends. As demands intensify in the future, recreational activities may conflict not only with other beneficial water uses, but among themselves.

Lastly, the Bay is a truly unique esthetic resource that will lose all value and importance without the continued maintenance of the system as a biologically productive one. In a decision-making process, economic values such as labor, capital, energy, material, products, and consumers are commodities and easily quantifiable values. Because we are not yet confident of our human judgment we tend to ignore those values which are not so readily quantifiable. The real result has often been that the quantitative factors are evaluated against nonquantitative factors on a quantified scale. Since nonquantifiable factors such as the future quality of life, natural and cultural diversity, and esthetics cannot be plugged into this system, the quantifiable factors become, in fact, the end or the goal of the decision-making process.

Biological Problems of the Chesapeake Bay

The biological problems of estuaries generally, and the Chesapeake Bay specifically, have been very well outlined in a host of publications including: *The Chesapeake Bay Plan of Study* (1970); Lauff (1967) (*Estuaries*); *A Symposium on the Biological Significance of Estuaries*, 1971; *Proceedings of the Governor's Conference on Chesapeake Bay*, 1968; *Eutrophication: Causes, Consequences, Correctives*, 1969; *A Research Program for Protection and Enhancement of the Biological Resources of the Chesapeake Bay*, 1971; *A Report of the Review Panel of the Smithsonian Institution*, 1971; *The Chesapeake Bay, Report of a Research Planning Study*, 1971; Schubel, (1972) (*The Physical and Chemical Conditions of the Chesapeake Bay: An Evaluation*); and Cronin, (1967) (*The Condition of the Chesapeake Bay*). Consideration of the data in these and hosts of other technical publications, combined with the knowledge of many of those persons who have had the greatest first-hand experience in dealing with the physical, chemical, and biological systems of the Chesapeake Bay, resulted in the rostering of causes of biological problems shown in Table 1. This listing, together with that of the geographical areas of greatest concern (Table 2), was prepared by The Research Planning Committee of the newly-formed Chesapeake Research Consortium, Inc. and resulted in the establishment of priorities for those critical problems of the Bay most in need of research emphasis.

Table 1.–Causes of biological problems in the Chesapeake Bay.

Material	Primary Sources/Causes	
Emissions and Additions to the Bay		
Nutrients	Municipal and domestic wastes, agriculture	
Sediments	Agriculture, urbanization, road building	
Biocides	Agriculture, pest control	
Metals	Industry, biocides, mining	
Petroleum	Boats, municipal and suburban runoff	
Radionuclides	Nuclear power plants	
Leachates	Land fills	
Other Chemicals	Industry, power plants	
Heat	Thermal discharges	
Exotic species	Introductions, deliberate or accidental	
Deletions from the Bay		
Process or product		
Fresh water diversion	Dams, consumptive use, Chesapeake & Delaware Canal	
Fishery products	Exploitation, poor fishing techniques	
Alterations of Wetlands, Shorelines and Shallows		
Process		
Shoreline erosion	Natural processes, wetlands destruction	
Habitat destruction	Dredging, dumping, filling	
Loss of productivity	Dredging, dumping, filling	
Flooding, sedimentation	Dredging, dumping, filling	
Cumulative Effects of Multiple Engineering Changes		
Process		
Erosion	Filling	Bulkheading
Sedimentation	Dredging	Piling placement
Habitat destruction	Groin construction	Construction
Loss of productivity	Spoil deposition	

These are (1) nutrient loading, (2) addition of hazardous substances, (3) sedimentation, (4) effects of engineering activities, (5) extraction of living resources, (6) problems resulting from alterations and destruction of wetlands, and (7) the impact of regional population growth and distribution. The following remarks relating to these priorities arose from the deliberations of the Chesapeake Research Consortium.

Dissolved nutrients play a fundamental role in the general food chain in large estuaries such as Chesapeake Bay. However, an excessive nutrient supply can, and often does, create undesirable effects by causing certain species to flourish at the expense of others. These perturbations, resulting in blooms and their associated by-products, are responsible for water-quality deterioration in many regions of the world. The best known and documented cases of the effects of excessive nutrient loading are found in fresh water streams and lakes and in low salinity parts of estuaries. Saline waters, however, are not exempt from blooms, though the biological participants are often quite different from the typical blue-green algae which causes problems in fresh water.

In Chesapeake Bay, the effects of nutrient loading from municipal and industrial wastes are most apparent in the upper Potomac and in Back River, the receiving waters for the wastes from the metropolitan Washington and Baltimore areas, and in the upper and lower James River, from the Richmond and Hampton Roads-Newport News regions. In the upper Potomac, levels of phosphorous are at disruptive levels even before the river reaches Washington, D.C., while in the tidal reaches the concentrations of total phosphorous and the ratio of nitrogen to phosphorous are considered to be characteristic of less productive, "unhealthy" waters. These high nutrient levels result intermittently in low concentrations of dissolved oxygen, and it has been estimated that in recent years dissolved oxygen levels during the summer months have retreated to the levels occurring in the early 1930's, prior to the installation of major treatment works for the Washington area (Wolman, 1971). Nutrient levels in Back River are very high, and the results of over-enrichment are intense. This estuary acts as a type of tertiary treatment pond and in this sense protects the main body of the Bay from the nutrient loading associated with municipal wastes from Baltimore (Schubel, 1972).

Dramatic rises in nutrient levels have recently been reported in the upper Patuxent (Flemer et al., 1970) where concentrations of nutrients now frequently reach levels comparable to those in the upper Potomac. This is mainly the result of a rapidly increasing population in the small drainage basin of the river. Local inputs from septic field drainage of largely unsewered land areas are observable in the smaller tributaries of the western shore. Nutrient inputs from agricultural areas are most noticeable from the Susquehanna, Northeast, and Bohemia Rivers.

In summary, the effects of the increased nutrients are concentrated in the upper reaches of the tributaries, and in the upper portions of the Bay. Nutrients are at undesirable levels in the upper Potomac and in Back River, and are near undesirable levels in the upper Bay, the Patuxent, the James, and in many smaller tributaries. Although most of the open Bay is currently in good condition, it is generally believed that the discharge of improperly treated sewage and municipal wastes constitute the most serious immediate threat to the Chesapeake Bay estuarine system (Cronin, 1967).

The problem of nutrient loading in Chesapeake Bay, particularly its tributary estuaries, is not new and is not likely to decline in the near future for several reasons. The population in the Bay region is growing and is predicted to continue to increase in the foreseeable future. Hence, additional waste loading from domestic and municipal treatment plants is a certainty. The nutrients provided from these sources, particularly phosphorus and nitrogen, not to mention a host of lesser items, will most likely increase faster than new, expanded, or upgraded treatment plants can be provided for removing them. Actually, significant removal of phosphorus and nitrogen from effluent requires tertiary treatment which is expensive and certainly not commonplace in future planning for the area—the Blue Plains Plant in Washington representing the exception. Simultaneously, increased attention is being given to the Bay and its tributaries for recreation, housing, and industrial activities by the nearby populace. This redistribution or crowding by the presently growing population will cause, and is causing, an intensification of the loading in close proximity to the Bay. In one form or another, population pressure is the major causal factor in the nutrient loading problem.

Concern about hazardous additions that are wasted to the Bay, and which might have lethal effects on the biota, has developed as the result of such observations as fish kills near Sparrows Point and other areas, oil spills at a number of locations around the Bay, and heavy metals found in shellfish. However, considerable uncertainty exists about the magnitude and effects of certain additions, since measurements of many of these materials have not been made until recently, and then only at a few locations. For example, the sources of heavy metals, the routes and rates of transport, the patterns and rates of accumulation in the sediments and the biota, and the biological effects are poorly known. There is very little published data on the occurrence of pesticides in the waters, sediments, or organisms of the Chesapeake Bay estuarine system, despite their wide-spread use and the tendency of some of the filter-feeding and deposit-feeding organisms to concentrate such materials. A number of oil spills have occurred in Chesapeake Bay but all have been minor. Oil from illegal pumping of bilges, oils, and greases in municipal wastes, and oil from filling stations that is washed into storm drains and eventually into the Bay, pose an increasing threat (Schubel, 1972). Evidence available from other areas suggests that significant effects on the exceptionally important biota of the Chesapeake Bay, and possible hazards to man, can be expected from the above materials under appropriate conditions, and that intensive evaluation of these inputs should be undertaken. In addition, preparations should be made to deal with new exotic additions as the need arises.

Pesticides have caused local mortalities of crabs in Virginia, and the capacity of oysters, clams, and other molluscs to extract some pesticides and concentrate them to 50-70,000 times above ambient concentration has caused continuing concern. A recent preliminary report from the Department of Natural Resources suggests that pesticides, especially chlordane, may be present in softshell clams at levels sufficient to injure the organisms and also make them totally unacceptable in interstate commerce as food. Longer-term observations on fish in the Potomac and Susquehanna Rivers do not disclose any dangerous pesticides at levels which threaten either the fish or human consumers. Pesticides do not now present a major problem in the Bay, but they merit thorough understanding because of the exceptional value and pesticide vulnerability of shellfish.

As indicated above, there is relatively little quantitative information available on the extent or effects of the addition of hazardous materials into Chesapeake Bay. The status of heavy metals is of particular concern because certain of these metals are highly toxic to plants and animals, including man, and they are highly persistent, retain their toxicities for prolonged periods of time, and generally function as cumulative poisons. The most toxic, persistent, and abundant heavy metals in the marine environment include mercury, arsenic, cadmium, lead, chromium, and nickel (Schubel, 1972).

There are very few data on the temporal and spatial distributions of any of the heavy metals in the Chesapeake Bay estuarine system or its tributary rivers. The unpublished work of Carpenter at the Chesapeake Bay Institute (discussed in Schubel, 1972) indicates that concentrations of heavy metals in the Susquehanna River are generally associated with concentrations of suspended sediments. The seasonality of both the total concentration and the solubilization of many metals suggests the significance of organic matter and metals derived from decaying vegetation. Vegetation in the drainage basin, then, may be a major source of heavy metal pollution to the Susquehanna and the upper Bay.

Relatively few measurements have been made of heavy metal discharges and of historical and geographical deposition in sediments. In the matter of discharges it is known that input estimates must take into account the variability of the source, and that small samples may be extremely misleading. In 2 studies of heavy metals in the Susquehanna, the estimated annual discharges of 3 common metals differed by more than an order of magnitude. Regarding spatial distribution, there are a few data that suggest there is a longitudinal gradient of heavy metals in the fine sediments of the Bay. Concentrations of heavy metals tend to be higher near the head of the Bay than further seaward in the estuary, apparently reflecting the different source materials from the Piedmont and Coastal Plain sediments and the removal of metals into sinks. The differences in the sources of organic matter may also be important in producing this gradient.

Temporal sedimentary records of heavy metal deposition are also scarce, but analyses to date do not demonstrate that man's activities have increased the levels of at least iron and zinc in portions of the upper Bay. Even the magnitude of man's activities relative to heavy metals in Baltimore Harbor is not clear in view of the wide variation (an order of magnitude in certain cases) in concentrations in contiguous areas.

In summary, because of their persistence and their toxicity at high concentrations, heavy metals are potentially dangerous pollutants. Heavy metals are introduced into the Bay in solution and adsorbed on fine particles, as a result of the natural processes of weathering and erosion. They are also introduced into the Bay as a direct and indirect result of man's activities. Man's use of heavy metals in pesticides, biocides, and industrial applications have tended to increase the inputs of heavy metals to the Bay, as have mining and agriculture in the drainage basin. Man's dam-building activities have tended to decrease the inputs. Dams on the lower Susquehanna trap large amounts of sediment and heavy metals, thus preventing them from reaching the Bay. The extent of man's impact on the spatial and temporal distributions of heavy metals in the Chesapeake Bay estuarine system is obscure.

Natural processes deliver millions of tons of sediment to Chesapeake Bay every year with water runoff from the entire watershed. These processes are being accelerated by earth-moving and construction, so that an estimated 8,000,000 tons/year enters the tributaries (Wolman, 1968). Dredging and spoil disposal practices contribute additional millions of tons to the problem, with further contributions coming from shore erosion from natural action and engineering activity.

Such sediments can have devastating effects on the uses of the Bay. Navigational channels are so filled as to require expensive dredging, recreational waters are made too shoal for use, and biological populations can be smothered or impaired.

Therefore, reasonable decisions must be made by management agencies about regulations on land use, on construction practices, on shore erosion control, and on the spoil disposal which is to be permitted. Each of these may involve large costs for landowners, construction firms, municipal, State and federal governments; and for many of those who use the Bay for related purposes. Management decisions must, therefore, be based on realistic understanding of the estuarine effects involved.

Very gross estimates have been made of the total input of sediment to the Bay from upland runoff and from marginal erosion. Schubel and Biggs (1969) estimated for the upper Bay that river-sourced sediment input is $0.6\text{-}1.0 \times 10^9$ kg/year, and Singewald and Slaughter (1949) showed that shore erosion contributes about 0.3×10^9 kg/year in the same area. Gaging stations and other local observations provide additional data, but the full annual budget for input distribution, deposition, resuspension in part, and other sedimentary patterns has not been determined.

Sherk and Cronin (1970) and Sherk (1971a, 1971b) have summarized available data on the effects of suspended and deposited sediments on estuarine organisms. Both field observations and laboratory experiments have been conducted on these effects, and there is strong evidence that sediments can reduce photosynthetic activity, kill benthic organisms, and seriously impair the welfare of eggs, larvae, and adults by sublethal damage. The review also demonstrated, however, that adequate prediction of sediment effects is rarely possible and that properly designed research is of exceptional urgency.

The fine sediments which are abundant in the Bay present enormous total surface area for sorption, and they have important roles in the removal and storage or later release of nutrients, toxic chemicals, and other materials.

Important engineering changes that have cumulative effects include filling principally around major cities, for parks, industry, housing, and airports; and the dredging that is associated with filling because of the necessity for deposition of spoil. These activities contribute to the problems of sedimentation and to the losses of productive wetlands and shallows.

The linkage of all of these problems to human population growth is obvious. It is also obvious, from perusal of Table II, that we have made the decision to eliminate several sub-estuaries as productive and esthetically pleasing parts of the Chesapeake Bay system. How many more we are prepared to sacrifice is an important and unanswered question.

As discussed above, there is a general understanding of the biological value of wetlands and their role as one of the 3 distinct production units involved in primary fixation of energy in estuaries (Odum and Smalley, 1957). An up-to-date, comprehensive review of marsh production, including a literature summary, has been presented by Keefe (in Flemer et al., 1970). It is apparent from this review that little work has been done on the biology of wetlands bordering the Chesapeake Bay, where situations vary widely in salinity regimes.

Turning to the significance of wetland sediment interactions, we know that marshes act as sources and sinks for sediments. The marsh surface itself is built by deposition of organic and inorganic sediments. Much of the inorganic sediment trapped in the marsh has its origin from the rivers tributary to the Bay. The marsh-derived organic sediment is largely the detrital vegetation which is transported via the marsh drainage system to the estuary (Odum and de la Cruz, 1967). The channels flooding and draining the marsh are thus the critical transport link in delivering detritus to the estuarine food chain. It may be anticipated that the drainage desnity (area/enclosed stream length) of a marsh determines, to some extent, the level of decomposition of detritus prior to its introduction to the system. At present we have a relatively poor understanding of the sediment transport processes within marsh channels and of the deposition or erosional characteristics of marsh surfaces. It is imperative that we understand more of the details of these transport processes if we are to specify the transport rates of detritus and nutrients.

Another major consideration is that of shoreline utilization. Although the possible management of marshes has received special attention, it is important to keep in mind that the marshlands are but one component of the broader question of shore line utilization and management. Since management agencies have (perhaps only temporarily) adopted a more conservative posture regarding alternate usage of marshes, the less biologically productive shoreline reaches are, and will continue to be, subject to additional stresses for development. The increasing concentration of the population near shorelines which generally have a high recreational appeal has made shorelines the most expensive property in the Bay region. This enhanced value has lead to a deeper awareness of the significance of shoreline erosion.

As in any resource problem, that of shoreline use is dynamic, since it is the result of many interacting factors that vary through time. However, a rather detailed understanding of the physical and biological processes and current land use is a prerequisite to the formulation of a shore utilization policy which will accomplish the desired objective. Specific actions are needed in the acquisition of baseline erosion data leading to recommendations for correction. Furthermore the research activities focused on understanding tidal river-bank erosion processes is needed for the improved design of river bank erosion control structures (Commonwealth of Virginia, 1971). Finally, it is very important to assemble for the land planners and managers the relevant data needed in shoreline planning. These data should include physical characteristics of the shoreline, the erosion rates, the key biological characteristics, current land use, and

Table 2.—Geographical areas of the Chesapeake Bay of particular concern for solution of biological problems

Area	Reason for concern	Immediacy of problems (if this is reason for concern)
	Maryland– Western Shore	
Susquehanna River	Nutrients, modification of fresh water flow, sediments, energy, fisheries	Freshwater flow–immediate: others–chronic
Bush River	Proposed thermal addition	Near term
Back River	Municipal waste, nutrients	Immediate
Patapsco River	Municipal and industrial wastes, dredging, spoil disposal, all hazardous materials	Chronic
Magothy, Severn and South Rivers	Residential wastes, agricultural runoff (nutrients), recreation	Chronic
West and Rhode Rivers	Protected area of low stress for baseline data and experimental study	
Calvert Cliffs	Thermal addition, radionuclides, political problems	Immediate
Cove Point	Proposed liquid natural gas terminal, dredging, spoil disposal	Immediate
Patuxent River	Thermal addition, nutrients, area of immediate stress	Immediate
	Maryland–Eastern Shore	
Chesapeake & Delaware Canal	Modification of freshwater flow, dredging and spoil disposal, shipping, oil spills	Immediate
Chester River	Heavy metals, biocides	Long range
Choptank River	Nutrients, sedimentation	Near term
Dorchester County	Shoreline erosion	Chronic
Maryland & Virginia		
Upper Tidal Potomac River	Urbanization, municipal wastes (nutrients), sediments, legal and institutional problems	Chronic
Lower Tidal Potomac River	Oil spills, dredging, fisheries	Near term
Lower eastern shore	Economy, agricultural wastes, wetlands, fisheries, erosion, access to water, industrial development	Immediate
	Virginia	
Rappahannock River	Freshwater flow modification, industrial wastes, area of relatively low stress, nutrients	Freshwater flow–immediate: others–chronic
Upper York River	Industrial wastes, freshwater flow modification wetlands, fisheries	Freshwater flow–immediate: others–chronic
Lower York River	Thermal addition, oil transport, dredging, spoil disposal, wetland alteration, fisheries, residential wastes, VIMS	Immediate
Upper Tidal James River (above Jamestown)	Industrial and municipal wastes, dredging, heavy metals, human health (bacterial counts)	Immediate
Lower Tidal James River (below Jamestown)	Industrial and municipal wastes, transportation (water & vehicular), spoil disposal, dredging, thermal addition, fisheries, heavy metals	Immediate and chronic
Hampton Roads	Transportation (water & vehicular), ship waste, spoil disposal, recreation	Immediate and chronic
Nansemond, Elizabeth and LaFayette Rivers	Heavy metals, municipal wastes, fisheries, urbanization, oil handling and transport, shipping, shoreline modifications	Immediate
Lynhaven system	Residential development, nutrients, shoreline modifications	Chronic
Bay-mouth area	Only exit from system to sea, sedimentation, fisheries (crab spawning area)	Near term

recommendations for siting specific activities which are based on the physical and biological characteristics.

The preceding comments on the biological problems of the Chesapeake Bay emphasize, I believe, that nutrient loading is the matter of primary concern and that this problem, like so many others, has resulted from a series of more or less unconscious decisions that continue to the present day. There are about 25 major subestuaries ringing the Bay. To reach this high count, I have included areas as small as the Middle River, north of Baltimore, with ones as large as the Potomac. Ten of these are presently affected by overenrichment to one degree or another. Four of them, the (upper) Potomac, the (upper) Patuxent, the Back, and the Patapsco Rivers, as well as the "Upper Bay", are so severely affected by nutrient loading that their productivity and esthetic qualities are impaired. Nonetheless, there has been no public outcry, and no formation of state-supported advisory committees like those relating to the siting of power plants in Maryland. This is of special interest in light of the *concensus opinion* that nutrient loading is *the major problem* affecting the Bay, and that sewage treatment plants are proliferating at a rapid rate. I have even heard complaints from a county official that a particular sewer main was carrying well below capacity volume; a matter that should be corrected forthwith by the adjustment in zoning that would permit new home construction.

Who is going to make the decision(s) concerning the number of subestuaries we should preserve? These are vital parts of the Bay, remarks concerning the usefulness of the Back River as a nutrient trap that protects "the Bay" notwithstanding. Who is going to make the decision about the upper level of nutrients that the entire system can tolerate? Perhaps we can only wait and see; it should not take very long.

Biological Research on the Chesapeake Bay

As a result of extensive research on this estuary, there has been accumulated a great deal of knowledge concerning the more than 2,000 species of plants and animals that we know to be important members of the Chesapeake Bay biological community and, concerning these, there has been developed in excess of 1,000 publications. Thus, we do know a great deal at the present time about the biology of the Chesapeake Bay. This knowledge has been obtained by investigators in a host of State and federal laboratories as well as those of a number of universities. In many instances, it has been research of an opportunistic nature evolving from the curiosity and interests of particular investigators concerning particular species or problems of biological interest. Much of it has also necessarily been research on economically important species. In regard to the latter, there have been certain constraints on the scope of the work in that it evolved around existing economic values; that is, economically important species concerned with the fishery resource. Thus, to a large extent, this research can be defined as autecology concerned with single taxa or groups of taxa. However, much of it has involved research more germane to an understanding of the Bay as a biological system and has resulted in some understanding of the interrelationships between many of the important biological species and the physical and chemical parameters that control their distribution and abundance. Consequently, enough has been learned about some natural and social systems for realistic selection and assignment of priorities. And, we have been able to supply to management and regulatory agencies much of the information they need regarding the sustained harvesting of economically important species, or the use of these in other ways. However, there has emerged from this background the unfortunate recognition that most of these studies have not been of the in-depth character needed for the solution of major environmental problems. This is not a phenomenon peculiar to the Bay; it is one that relates equally to other large scale biological-physical systems. Even if we had long ago comprehended the Bay as a large, intricately interrelated system of physical, chemical, and biological units, we would not have studied it as such because the demand for such elaborate consideration was not necessary, and the funds, personnel and expertise were not available. The Bay, like other large systems, had in the past the resiliency to withstand the environmental insults to which it was being subjected without a significant or appreciable loss in (1) its biological productivity, (2) its use as a recreational resource, or (3) in loss of its esthetic value. Now, however, in many of the subestuarial systems which form the bulk of the biologically productive parts of the Bay, we are alarmed by gradual changes related to social development and economic growth which may or may not be irreversible, which have reduced biological productivity, and which have reduced the use of these systems for recreational purposes, and have made them esthetically displeasing. We are alarmed because we know that we do not have the data necessary for the solution of large scale environmental problems. We recognize that there are a very large number of known and unknown independent variables which must be uncovered and, although we already possess some of the legal machinery necessary to regulate the quantities of nutrients, industrial wastes, sediments, toxic chemicals, heat, and so on that may be delivered to the Bay, we do not know all the organisms involved in the food webs, their responses to natural and man-induced pertubations and their short and long term interactions. Further, we know very little about the cumulative and synergistic effects of diverse uses. Unless we decide what changes may be acceptable, it will be impossible to say "how much" or "how long". In such an atmosphere of ignorance of quantitative limits public support can be dissipated into rather non-essential, but highly visible directions while basic but more complex problems progress unchecked to crisis proportions. We recognize that the Chesapeake Bay is a vastly complex system and that its tributaries and watersheds, its terrestrial and aquatic populations, including human populations, collectively present a formidable open-ended study that could quite literally involve thousands of investigators and tens of millions of dollars for an indefinite time. Unless some priorities are established in the direction of our research efforts, it is quite conceivable that many of the irreversible and sometimes catastrophic consequences of man's intrusion on the ecosystem will come about long before the system can be described, much less understood.

An Approach to the Solutions of Biological Problems in the Chesapeake Bay

The States of Maryland (Department of Natural Resources, Department of Planning) and Virginia (Marine Resources Commission, Virginia Institute of Marine Science) have the *major* management responsibilities for the Chesapeake Bay. The basic objectives of State management of the Bay are difficult to make explicit, but they can be expressed in the most general terms as the maintenance or increase of the following overlapping Bay attributes: health, productivity, safety, cleanliness, and esthetic quality. The translation of these generalities into operationally useful objectives moves on to categories such as: maintenance of biological stability and protection of the capacity of the system to recover from perturbations (health), maintenance or increase in the yields of desired species (productivity), removal of hazards to human health and well being (safety), achievement and maintenance of politically determined water quality standards (cleanliness), and maintenance of indirectly expressed standards of sensible parameters (esthetic qualities). All of these categories admit to measurement, and become operationally useful to the extent that they are measured and measurable. The question becomes one of how do we make the critical measurements, and how do we make them operationally useful?

Estuarial managers frequently lament that they lack sufficient biological information for solving key resource management problems. The obvious solution to this deficiency is to identify problems in advance, determine the kinds of information necessary to solve those problems, and launch data collection and research necessary to produce this information, to be available when needed (Jenkins, D.W., personal communication).

This exercise is as difficult as it is obvious. Problem identification involves making predictions about the future that are necessarily tenuous, considering the pace of technological change. Once problems are identified, the kinds of information necessary for their solution are by no means self-evident. Identification of information useful to making a decision implies the existence of an explicit decision-making process which can seldom be found, let alone described, outside a resource allocation textbook. Finally, there is the difficulty of linking specific research to specific management-information needs. The complexity and interrelatedness of the biological system suggests the necessity of having a total systems predictive capability before important decisions can be based on firm biological evidence.

Notwithstanding these difficulties, the exercise is presumed to be a useful one. It would require management to state as explicitly as possible its anticipated information needs, with the scientific community responding as to how this information could be produced. The cycle would be completed if management then solicited and received public funds for the generation of this information, and called upon scientists for the conduct of the necessary research.

How has this approach actually worked in practice? There is presently minimal coordination between the hosts of federal, State, university, and private laboratories conducting research on the Chesapeake Bay, and the bulk of these are not responsive to the urgent needs of the regulatory and management agencies of Maryland and Virginia. Further, it is not always clear just which federal or State management agency has primary responsibility or authority for a particular area of concern. Thus, it becomes apparent that a central research organization, with a program designed to meet the needs of management, be clearly identified, and that this research group be responsive to at least the State agencies with primary management and regulatory responsibility. Such a step has been taken in the formation of the Chesapeake Research Consortium, Inc., with support from the National Science Foundation. The member institutions of this consortium include The Johns Hopkins University, The University of Maryland, The Virginia Institute of Marine Science, and the Smithsonian Institution. Thus, not only is the bulk of Chesapeake Bay expertise made available from a host of institutional departments, but the central bayside laboratories are also included. This consortium is open-ended, it will enlarge, and it has the promise of providing the properly coordinated scientific program so vital to the future of the Bay.

Solution of the complex problems of the Bay requires an approach that is novel to most investigators. Interdisciplinary teams, including economists, sociologists, attorneys, land-planners, representatives of industry, and biological and physical scientists, must be assembled for work on well-defined problem areas. The planning of the program must include representatives of regulatory and management agencies, and their participation should result in the collection and availability of that data most needed for immediate decisions concerning immediate problems. The highest priority must be for directed research designed specifically for problem solving, and this research must be rigidly programmed and directed. Basic research is needed for the identification of problems not yet identified, but limitations of personnel, time, facilities, and money demand that priority be given to directed research on already well-identified or anticipated problems whose solution is mandatory. Only in this way will we ever achieve any success in the balancing of the conflicting uses of the Bay, and the establishment of those policies that will protect the Bay as a multiple use resource. Information presented earlier clearly indicates that present legal authority, e.g., the Wetlands Acts of Maryland and Virginia, the Power Plant Siting Act of Maryland, the Federal Water Pollution Control Act, the proposed Federal Toxic Substances Control Act, and many others, is insufficient to cope with management problems, particularly at the local level.

Finally, there is a distinct need for the development of a methodology that produces data sufficiently adequate to cope realistically with the problems of such a vast natural system. Since we obviously cannot study all areas and all problems with equal intensity, a bonafide case must be made for the validity of extrapolating from locally derived results to arrive at some understanding of effects on the Bay as a whole. If a small change or a multiplicity of small changes in one locale has a given effect, what is the cumulative effect of a host of such changes in comparable communities within the entire system? Secondly, we must use the available knowledge and supplement it with that which is lacking (i.e., largely the separation of effects deriving from natural as distinct from unnatural perturbations, and the rather different information derived from interdisciplinary research that is temporally and spatially coincident) to establish clearly what sorts of change(s) result from what type(s) of alteration(s) to carefully selected areas. Empirical data gathered in these areas, *combined* with results from experimental manipulations, will enhance the possibility of success.

Man-induced, deleterious changes in major natural systems are traditionally subtle, difficult to detect and measure, and they often confound us in our efforts to establish definitive cause and effect relationships. This is true because measurable changes usually result from the cumulative effects of small perturbations seemingly insignificant as isolated events, occurring over long periods of time. When the major natural system is a land-water complex as vast as the Chesapeake Bay and its drainage basin, the detection and solution of environmental problems becomes especially difficult. This methodology should be of major assistance in overcoming these problems.

None of these proposals has referred to the role of the political process in making decisions concerning the use of natural resources. We can reasonably assume that all decisions result from assessments of conflicting benefits and costs, and that those which approach cost-benefit equality and involve conflicting values and non-quantified elements become extremely difficult and contentious. Unfortunately, decisions based on the benefits to be derived from a particular use of any component of the Bay, or a component of any other large and complex natural system, are often or usually removed in time from an assessment of the costs. Immediate economic gain (benefits) is understood by everyone, but cumulative harmful effects (costs) are not nearly so easy to elucidate. Compounding this problem is the role of political expediency in decision making, and the fact that this often renders the best efforts of everyone to absolute zero. Since this is the case, our best efforts must be made even better.

Summary

What we term the Chesapeake Bay is actually a vast natural system that has, because of size and peculiar biological and phyiscal attributes, been able to withstand and/or recover from, a large number of deleterious, man-induced perturbations. These changes have been difficult to separate from natural processes that also change the character of the Bay, many of which have been accelerated by man's activities. It is now possible to detect gross changes in the Bay that include the virtual extinction of several subestuaries as biologically and estheticly useful resources. These events are foreboding in that we can foresee the possibility of their continuing unchecked until the entire Bay is similarly affected.

The Chesapeake Bay has enormous biological, and thus economical, significance in terms of the large commercial fishery, and its use as an esthetic and recreational resource. The longevity of all of these things depends upon the continued maintenance of the physical and chemical integrity of the Bay, i.e., maintenance in a state that supports all of the trophic levels and relationships.

The principal biological problems of the Bay result from excessive nutrient loading, the addition of hazardous materials, erosion and sedimentation, the cumulative effects of engineering activities, the exploitation of living resources, and the alteration and destruction of the wetlands. All of these things are related to the impact of human population growth in the Chesapeake Bay Region, and the conflicting demands placed by these people on a multiple-use resource.

Previous biological research on the Chesapeake Bay has been inadequate in failing to

provide much of the information needed by management and regulatory agencies. This has resulted primarily from failure of the approach used to deal effectively with the Bay as a large interrelated system, and thus to identify all of the key organisms in food webs, their responses to natural and man-induced perturbations, and their short and long term interactions. Little is known about cumulative and synergistic effects of diverse uses of the Bay, what changes are acceptable, and the establishment of quantitative limits.

There is a distinct need for the management agencies of Virginia and Maryland, as well as those of the Federal government, to join with the academic community in an effort to obtain the information needed for decision-making, and to do this in as expeditious a manner as possible. This effort will require a major interdisciplinary approach based on a sound methodology that can deal constructively with the complex problems of the Chesapeake Bay.

References Cited

Beers, R.F., Jr., et al. 1971. The Chesapeake Bay: A research program to assist in better management of complex environmental systems. Johns Hopkins University, University of Maryland, VIMS. xiii + 211 pp.

Berger, B.B., et al. 1971. Report of the review panel of the Smithsonian Institution on a research program for protection and enhancement of the biological resources of Chesapeake Bay. 19 pp.

Caspers, H. 1967. Estuaries: Analysis of definitions and biological considerations. p. 6-9 *In* Lauff, G.M., (Ed.) Estuaries. Amer. Assn. Adv. Sci. Pub. 83, Washington, D.C. 757 pp.

Cronin, L.E. 1967. The condition of the Chesapeake Bay. Trans. 32nd N.A. Wildlife and Natural Resources Conf., Wash. D.C., pp. 138-150.

Cronin, L.E., and J.J. Mansueti. 1971. The biology of the estuary, pp. 14-39. *In* A Symposium on the Biological Significance of Estuaries. Sponsored by the Sport Fishing Inst. in cooperation with Sportsmen's Clubs of Texas, Inc. and Nat. Wildlife Fed. xi + 111 pp.

Douglas, P.A., and R.H. Stroud. 1971. A symposium on the biological significance of estuaries. *Ibid*., xi + 111 pp.

Flemer, D.A., D.M. Hamilton, C.W. Keefe, and J.A. Mihursky. 1970. The effects of thermal loading and water quality on estuarine primary production, NRI, Ref. 71-6.

Hargis, W.J., Jr., and B.L. Laird. 1971. The environmental resource-use and management needs of the Coastal Zone. Spec. Sci. Rep. No. 57, Virginia Inst. of Marine Science.

Lauff, G.M. (Ed.). 1967. Estuaries. Amer. Assn. Adv. Sci. Pub. 83. Washington, D.C. 757 pp.

Masmann, W.H. 1971. The significance of an estuary on the biology of aquatic organisms of the Middle Atlantic Region. pp. 96-109. *In* A Symposium on the Biological Significance of Estuaries, sponsored by the Sport Fishing Inst. in cooperation with the Sportsmen's Clubs of Texas, Inc., and the Nat. Wildlife Fed. xi + 111 pp.

McHugh, J.L. 1966. Management of estuarine fisheries, pp. 133-154. *In* A Symposium on Estuarine Fisheries. Spec. Pub. No. 3. Amer. Fisheries Soc. Washington, D.C.

______________. 1967. Estuarine nekton, pp. 581-620. *In* Lauff, G.M. (ed.). Estuaries. Amer. Assn. Adv. Sci. Pub. 83. Washington, D.C. 757 pp.

National Academy of Sciences. 1969. Eutrophication: causes, consequences, correctives. (Symposium proc.). Nat. Acad. Sci., Washington, D.C. 659 pp.

Odum, E.P., and A.A. de la Cruz. 1967. Particulate organic detritus in a Georgia saltmarsh estuarine ecosystem, pp. 383-388. *In* Lauff, G.M. (ed.). Estuaries. Amer. Assn. Adv. Sci. Pub. 83. Washington, D.C. 757 pp.

Odum, E.P., and A.E. Smalley. 1957. Trophic structure and productivity of a salt marsh ecosystem. Progress Report, N.S.F.

Proceedings of the Governor's Conference on Chesapeake Bay, 1968. 218 pp.

Schubel, J.R. 1972. The physical and chemical conditions of Chesapeake Bay: an evaluation. Spec. Report, 21. Chesapeake Bay Inst., 73 pp.

Schubel, J.R., and R.B. Biggs. 1969. Distribution of Seston in Upper Chesapeake Bay. Chesapeake Science 10: 18-23.

Sherk, J.A., Jr. 1971a. The effects of suspended and deposited sediments on estuarine organisms–Literature summary and research needs, Ches. Biol. Lab. Contributions, 443. 73 pp.

______________. 1971b. The effects of sediments in the marine environment including estuaries. Report to Panel on Water Quality Criteria for Marine Aquatic Life and Wildlife, Nat. Acad. Sci. CBL Ref. 71-93. 37 pp.

Sherk, J.A., Jr., and L.E. Cronin. 1970. The effects of suspended and deposited sediments on estuarine organisms–an annotated bibliography of selected references. CBL Ref. No. 70-19. 61 pp.

Singewald, J.T., and T.H. Slaughter. 1949. Shore erosion in tidewater Maryland. Md. Dept. Geol., Mines, and Water Res. Bull. 6. 141 pp.

Stross, R.G., and J.R. Strottlemeyer. 1965. Primary production in the Patuxent River. Chesapeake Sci. 6: 125-140.

Stroud, R.H. 1965. Chesapeake Bay Fishing. SFI Bull. 164: 6.

________________. 1971. Introduction. *In* Douglas, P.A., and R.H. Stroud. Symposium on the Biological Significance of Estuaries. Sponsored by the Sport Fishing Inst. in cooperation with Sportsmen's Clubs of Texas, Inc. and Nat. Wildlife Fed. xi + 111 pp.

The Chesapeake Bay Plan of Study. 1970. Corps of Engineers and Advisory Group to the Chesapeake Bay Study. iv + 95 pp.

Wass, M.L., and T.D. Wright. 1969. Coastal Wetlands of Virginia. Interim Report to the Governor and General Assembly; VIMS. No. 10. x + 154 pp.

Wolman, M.G. 1968. The Chesapeake Bay: Geology and Geography, Proc. Gov. Conf. on Chesapeake Bay. pp. 11-48.

________________. 1971. The nation's rivers. Science 174: 905-918.

The Fate of the Chesapeake Bay: Socio-Economic Aspects

John J. Boland[1]

Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, Md. 21218

ABSTRACT

Much of the attention directed to the Chesapeake Bay is quite properly concerned with the response of the Bay's natural systems to the industrial, recreational, and other uses which are made of its waters and shorelands. Another aspect of the problem lies in the nature of the social and economic systems whose functioning is known to affect the Bay. This paper describes a study of the electric generating industry in the Chesapeake Bay region, now underway. The purpose of the study is to learn how that industry can be expected to respond to policies regarding the use of the Bay as a heat sink. Specific investigations include analyses of future electric energy demands, future demands for generating sites, and the role of public policy in siting new generating facilities.

The Chesapeake Bay as a Resource

It must strike the participants in this Symposium as self-evident that the Chesapeake Bay is a natural resource of inestimable value. This follows, not from any mind-boggling list of numbers and varieties of species of life found in its waters, but from its enormous capacity for making this part of the world a better place to live, now and in the future.

We have grown accustomed to using the Bay for many things. It supports a wide variety of recreational and leisure-time activities—those of us fortunate enough to live near its shores are constantly aware of even the visual pleasures it affords. The Bay provides some of the more delectable items in our diet from its range of harvestable finfish and shellfish. It is an important water transportation route. Its abundant waters have supported the growth of a large and diversified industrial community in Maryland and Virginia, in part by offering a sink for the

[1] Mr. Boland is an environmental engineer with a background in economics and public administration. His professional career includes local government service in the municipal public works field. He was Chief of Utility Operations for Anne Arundel County, Maryland. More recently, he served as Chief, Water Resources Section, Hittman Associates, Inc., offering consulting services to various levels of government in the water resource management field. Mr. Boland received his B.E.E. (Electrical Engineering) from Gannon College, Erie, Pa., and his M.S. (Government Administration) from George Washington University, Washington, D.C. He is presently a Ph.D. candidate at the Johns Hopkins University, where he serves as a research associate on the study entitled "Economic Considerations in Power Plant Siting in the Chesapeake Bay Region." This research is supported by the State of Maryland and the U.S. Atomic Energy Commission.